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EVALUATION OF EXPANDED BEAD POLYETHYLENE FOAM CUSHIONING FOR PA--ETC(U)
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RICHARD V. BROWN
Mechanical Engineering Technician
Autovon 787-4519
Commercial (513)257-4519

Final rept.

EVALUATION OF EXPANDED BEAD POLYETHYLENE FOAM CUSHIONING FOR PACKAGING

HQ AFALD/PTP
Air Force Packaging Evaluation Agency
Wright-Patterson AFB OH 45433

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ABSTRACT

Expanded Bead Molded Polyethylene Foam Cushioning Material was evaluated for its static and dynamic characteristics. It was determined that the material meets the compression set and compressive strength requirements of Type I material of PPP-C-1752A, "Cushioning Material, Packaging, Unicellular Polyethylene Foam, Flexible." The material provides slightly better dynamic cushioning in the optimum cushioning static stress range than conventional polyethylene sheet stock materials. Application of molded polyethylene should prove to be cost effective when used in lieu of built-up cushion packs or container structures which are formed by laminating together pieces of polyethylene sheet stock.

PREPARED BY:

RICHARD V. BROWN, Mechanical Eng. Tech.
Materials Engineering Division
AF Packaging Evaluation Agency

REVIEWED BY:

MATTHEW A. VENETOS
Chief, Material Engineering Division
AF Packaging Evaluation Agency

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28 NOV 1979

APPROVED BY:

J. E. Thompson

JACK E. THOMPSON
Director, Air Force Packaging
Evaluation Agency

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A

INTRODUCTION

At the present time, polyethylene foam is being used for cushioning and blocking and bracing of various items in containers. In some Air Force transportation packaging order (TPO) packs polyethylene foam sections are frequently cemented together in various thicknesses and then cut to the shapes desired. Either because of poor bonding or repeated use, these sections sometimes separate and are lost. In the case of the TPO pack for the LN-15 Inertial Measurement Unit (IMU), it was found that the top polyethylene pad in the inner container became uncemented (see Fig 1 and 2) making it impossible to remove the item from its container without tilting the container

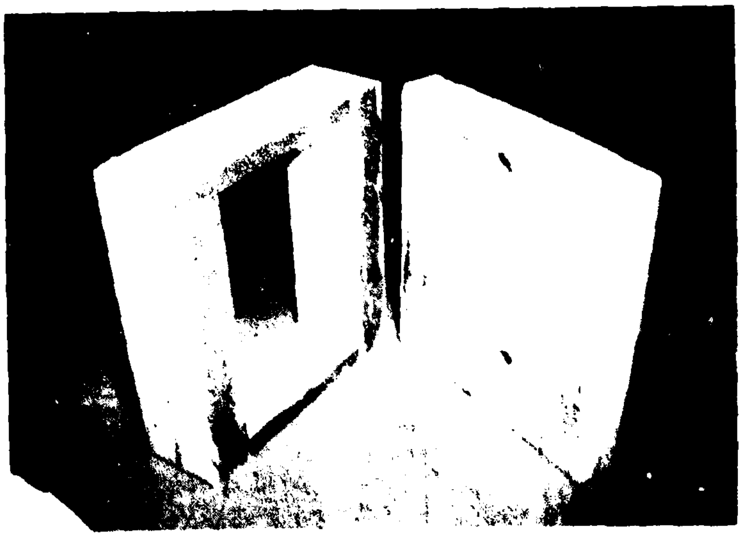


Figure 1. Cement bond failure in the top pad of an LN-15 pack.

Figure 2. LN-15 difficult to remove because of bond failure of the polyethylene pad

upside down at an angle and sliding the item out. If this is not done carefully, damage can result to this fragile and expensive item. A possible solution to this and other packaging problems would be to use molded pieces of polyethylene.

At the present time a molded polyethylene material, tradename EPERAN, is manufactured only in Japan. However, there are plans to manufacture EPERAN IN THE United States if sufficient market volume can be developed.

The Kaneka America Corporation has furnished this Agency with considerable technical data on "EPERAN" including graphs and tables of performance data. English translations of this data can be obtained from AFALD/PTPT, WPAFB OH 45433.

OBJECTIVE

The objective of this study was to evaluate the static and dynamic characteristics of 2.0 lb/ft^3 (0.034 gm/cm^3) density EPERAN (expanded bead polyethylene foam) and determine its potential use as a cushioning and/or blocking and bracing material in package designs for DOD equipment.

MATERIAL DESCRIPTION

"EPERAN", a foam polyethylene first developed by Kanegafuchi Chemical, is formed by the internal molding of polyethylene beads. It can be produced in practically any desired shape (see Fig. 3) by a completely automatic molding process. The material is white in color, odorless, clean, and has a "spongy" feel to it. Some of the advantages claimed for EPERAN are:

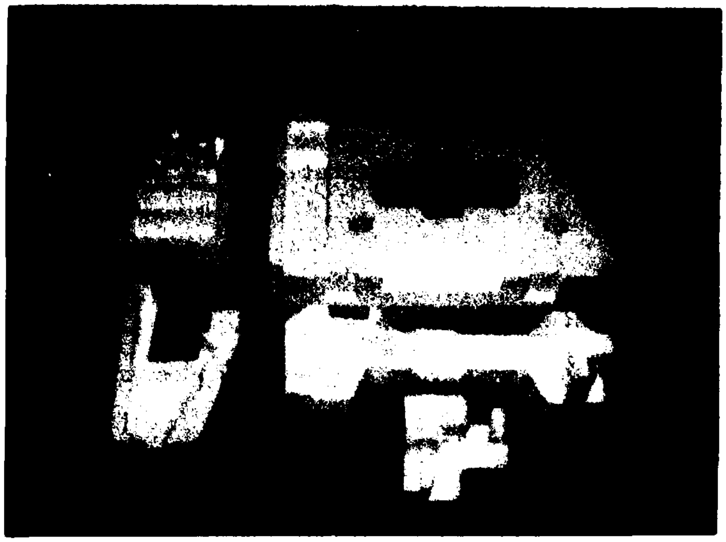


Figure 3. Various Shapes of Molded Eperan

1. Moldable to practically any shape.

2. Can be cut, and cemented if necessary.

3. Consistent properties.

4. Can be produced in variable densities.

5. Outstanding shock absorbent characteristics which decline little as a result of repeated impact.

6. Oil, chemical, and weather resistant.

7. Good surface protection - soft and pliable.

8. Does not produce black smoke or toxic gases when burned.

9. Eperan can be obtained in various densities ranging from 1 lb/ft^3 (0.016 gm/cm^3) to 6 lb/ft^3 (0.096 gm/cm^3) by varying the amount of expansion of the polyethylene beads. The standard material densities available are 2.0 lb/ft^3 (0.034 gm/cm^3) and 5 lb/ft^3 (0.08 gm/cm^3) obtained through bead expansion of 27 and 15 fold respectively. The data from the manfacturer on static and dynamic characteristics primarily dealt with the 2.0 lb/ft^3 material. The material evaluated in this study was also limited to that denisity.

TEST SPECIMENS

The molded polyethylene foam material provided was in sheet thicknesses of 1, 1.6, 2, 2.4 and 3 inches (2.45, 4, 5.06, 6, and 7.62 cm

respectively). Samples of molded corner pads were also furnished. Those pads, measuring 0.79 inch (2 cm) in thickness, were tested in completed pack configurations.

TEST EQUIPMENT AND INSTRUMENTATION

The following equipment and instrumentation were used to conduct the tests:

Equipment

"Hardigg" Cushion Tester, Model No. 3

Drop Tester, Model 125 DTP, Gaynes Engineering Company

Instron Tensile/Compression Tester, Model TTC

Instrumentation

Accelerometer, $\pm$ 100 G, Type A5A-100-350, Statham Instruments

Power Supply, Model RM-6, Sensotec Inc.

Accelerometers (3 ea), Model 2233E, Endevco Corp.

Charge Amplifiers (3 ea), Model 26514C, Endevco Corp.

Power Supply, Model 2622C, Endevco Corp.

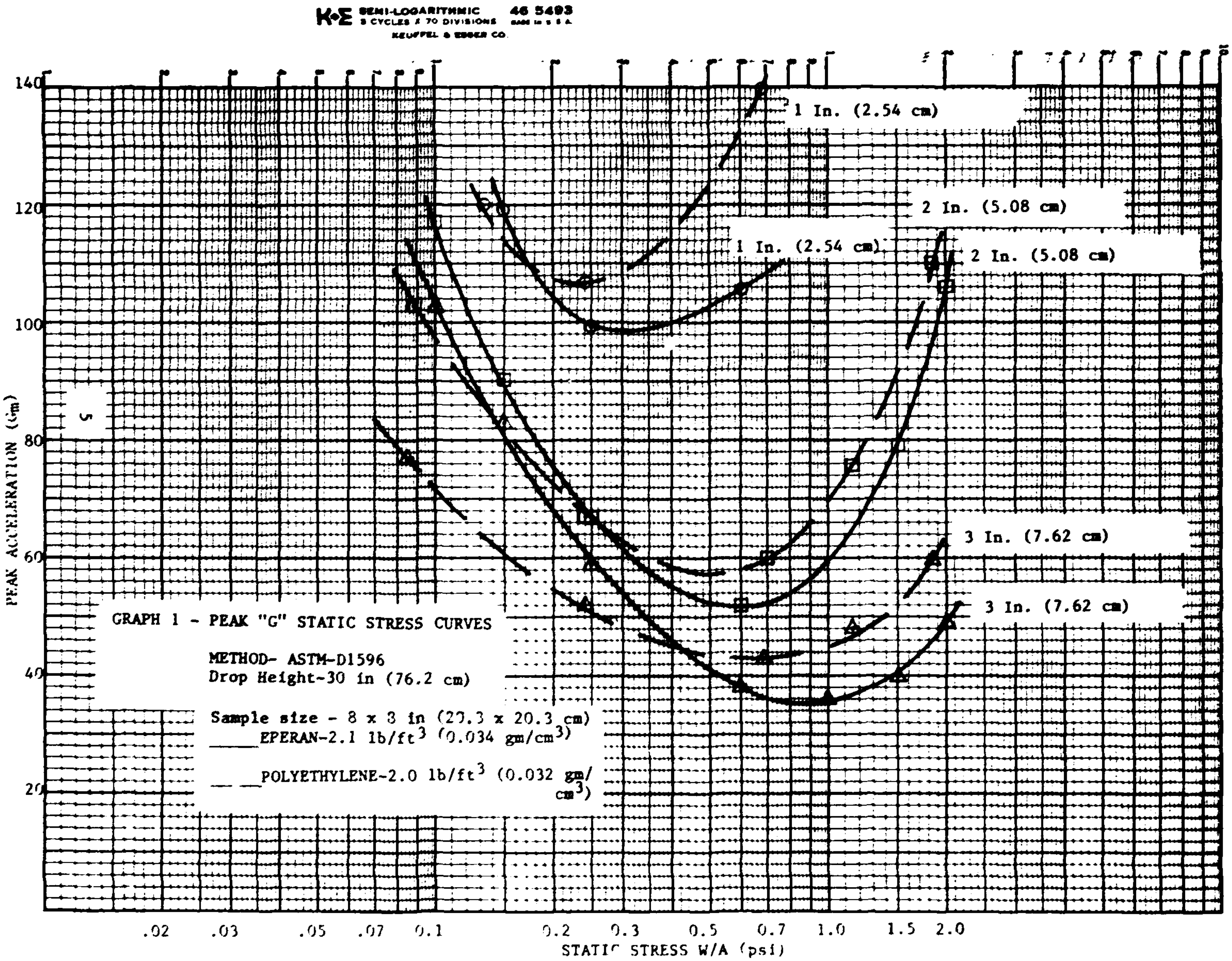
"Storage" Oscilloscope, Type 565B, Tektronix

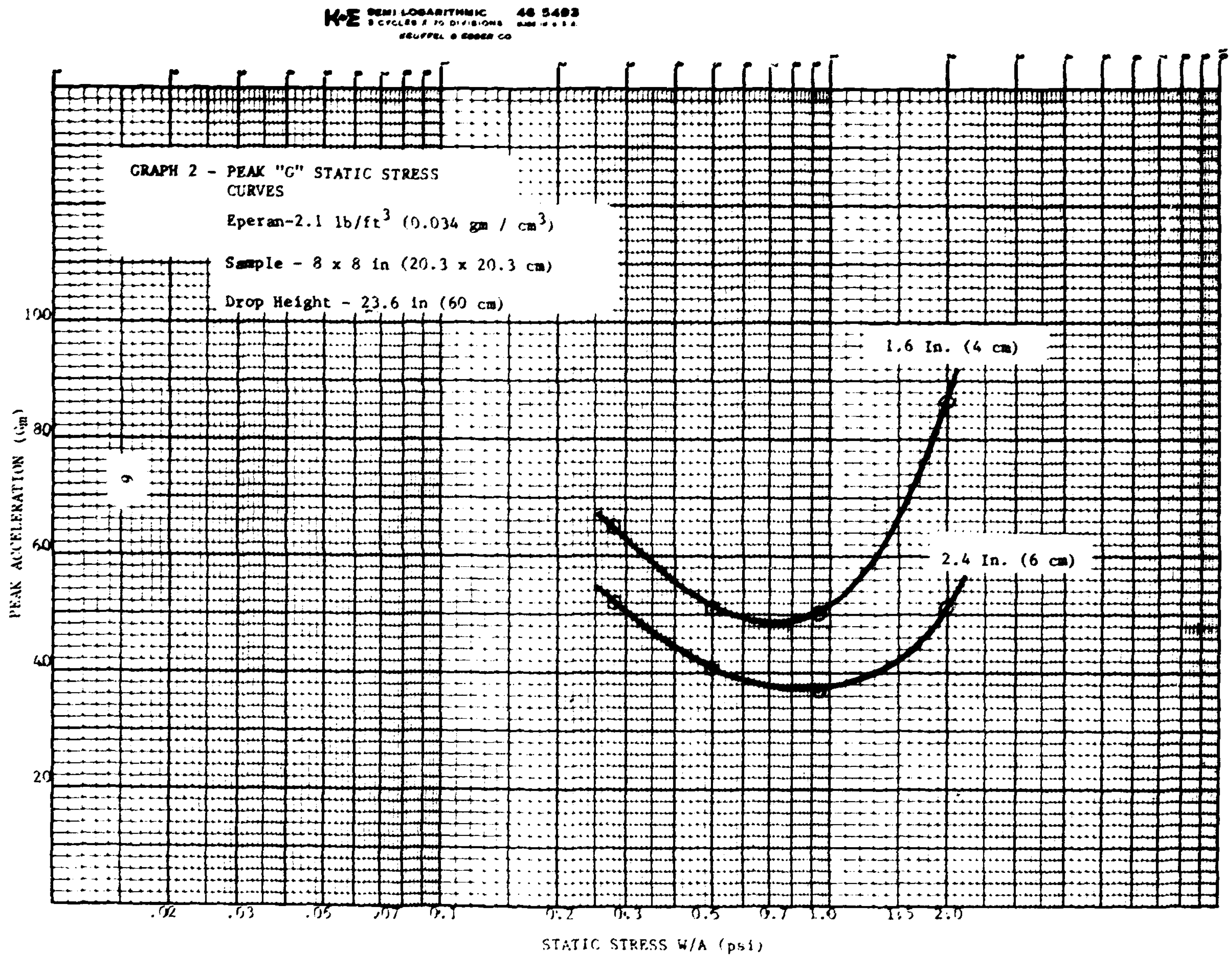
TEST PROCEDURE

Dynamic Cushioning Test

Peak G - static stress curves (Graph 1) were developed in accordance with ASTM-D1596, "Shock Absorbing Characteristics of Package Cushioning Materials". Three 8" by 8" samples of each thickness, 1, 2, and 3 inch, were conditioned at 72°F, 50% RH for at least 24 hours. The density of each sample was calculated prior to conducting the impact test. A drop height of 30 inches was used. Five drops were made on each sample at intervals of at least one minute between drops to allow for specimen recovery. The first recorded peak "G" on each sample was ignored but the remaining four values were averaged. Then the averages of the three samples were combined to determine a static point for plotting. The same samples were used throughout the tests required to establish a complete curve.

The same procedure was used to develop Peak G - static stress curves (Graph 2) for the 1.6 and 2.4 inch thicknesses of material at a drop height of 23.6 inches (60 cm).


K•E SEMI-LOGARITHMIC 3 CYCLES X 70 DIVISIONS
46 5493
KEUFFEL & ESSER CO.
1 In. (2.54 cm)
2 In. (5.08 cm)
1 In. (2.54 cm)
2 In. (5.08 cm)
3 In. (7.62 cm)
3 In. (7.62 cm)
GRAPH 1 - PEAK "G" STATIC STRESS CURVES
METHOD- ASTM-D1596
Drop Height-30 in (76.2 cm)
Sample size - 8 x 3 in (20.3 x 20.3 cm)
EPERAN-2.1 lb/ft3 (0.034 gm/cm3)
POLYETHYLENE-2.0 lb/ft3 (0.032 gm/cm3)
PEAK ACCELERATION (Gm)
140
120
100
80
60
40
20
.02
.03
.05
.07
0.1
0.2
0.3
0.5
0.7
1.0
1.5
2.0
STATIC STRESS W/A (psi)


K+E SEMI-LOGARITHMIC 46 5493
GRAPH 2 - PEAK "G" STATIC STRESS CURVES
Eperan-2.1 lb/ft3 (0.034 gm / cm3)
Sample - 8 x 8 in (20.3 x 20.3 cm)
Drop Height - 23.6 in (60 cm)
1.6 In. (4 cm)
2.4 In. (6 cm)
PEAK ACCELERATION (Gm)
100
80
60
40
20
.02
.03
.05
.07
0.1
0.2
0.3
0.5
0.7
1.0
1.5
2.0
STATIC STRESS W/A (psi)

Completed Pack Tests (corner pads)

Two sets of molded corner pads were tested in a completed pack configurations to determine their dynamic cushioning performance. A set of eight molded corner pads, 0.79 inch (2 cm) thick with a base area of 7.4 in^2 (48 cm^2), was placed on the corners of a rectangular shaped wood test load (see fig. 4) with dimensions of 17 x 11 x 9 inches (43.2 x 27.9 x 22.9 cm) and weight of 13.5 lbs (6.13 kg). The cushioned load was placed in a single wall domestic grade fiberboard container. The container flaps were closed with 3-inch wide tape (PPP-T-60D, Type III, class 1). The test load was instrumented with three triaxially mounted accelerometers placed at the center of gravity of the load.

The drop tests were conducted in accordance with Fed. Test Method Std. No. 101B, Method 5007 except for the order of drop. A total of 30 drops were made, 5 drops on each face. The drops alternated between opposite faces until 10 drops had been conducted. This test sequence was repeated on the other 2 sets of opposite faces. The Peak G values were displayed on the oscilloscope. The drop tests were conducted from heights of 15.7 inches (40 cm) and 19.7 inches (50 cm) using one set of corner pads. At the completion of these drops, the container was dropped from a height of 19.7 inches (50 cm) on corners and edges. The load weight stressed the corner pads to 0.46 lb/in^2 (0.03 kg/cm^2), the optimum cushioning point of the dynamic Peak G vs. Static Stress curve for the material. The weight of the load was increased to 25 lbs (11.35 kg) and the flat face drops repeated using new corner pads. This weight stressed the corner pads to 0.84 lb/in^2 (0.06 kg/cm^2).

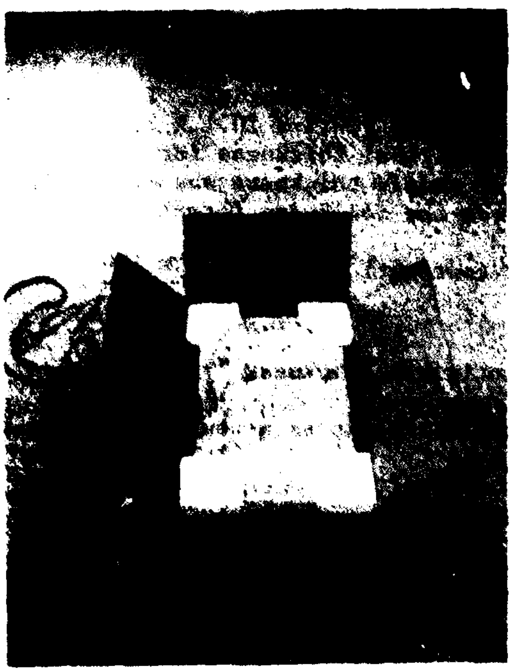


Figure 4. Molded Corner Pads

Corner pads fabricated "in-house" were also evaluated. The pads, of both 1.6 inch and 2.4 inch (4 and 6 cm) thick EPERAN, were cut and glued from flat sheet stock. The dynamic performance of these corner pads were compared with the predicted performance based on the Peak G versus Static Stress curves developed using the ASTM-D1596 test method. The area of each face of pads was approximately 6.8 in^2 (43.9 cm^2). The 25 lb (11.35 kg) load used for drop testing stressed the material to 0.92 lb/in^2 (0.064 kg/cm^2).

Each set of corner pads was subjected to the same test procedure of 30 drops as described previously and also dropped on all eight corners and twelve edges. An additional drop sequence of an impact on four corners and two edges was also made.

Static Compressive Stress-Strain Curve

The stress-strain data (Graph 3) was developed using the method described in MIL-HDBK-304A "Military Standardization Handbook, Package Cushioning Design". Three samples, 4 x 4 x 2 inches (10.2 x 10.2 x 5.1 cm) were conditioned at least 48 hours at 72°F, 50% RH. The samples were then compression cycled 10 time, 65% of their original thickness at a 10 inches per minute loading rate. One hour after cycling, the thickness of each sample was measured under a preload of 0.025 lb/in^2 (0.002 kg/cm^2) and then a load-deflection curve was generated at a one inch (2.5 cm) per minute loading rate. This data was then converted to a stress-strain curve. The data developed on three samples was averaged to produce Graph 3.

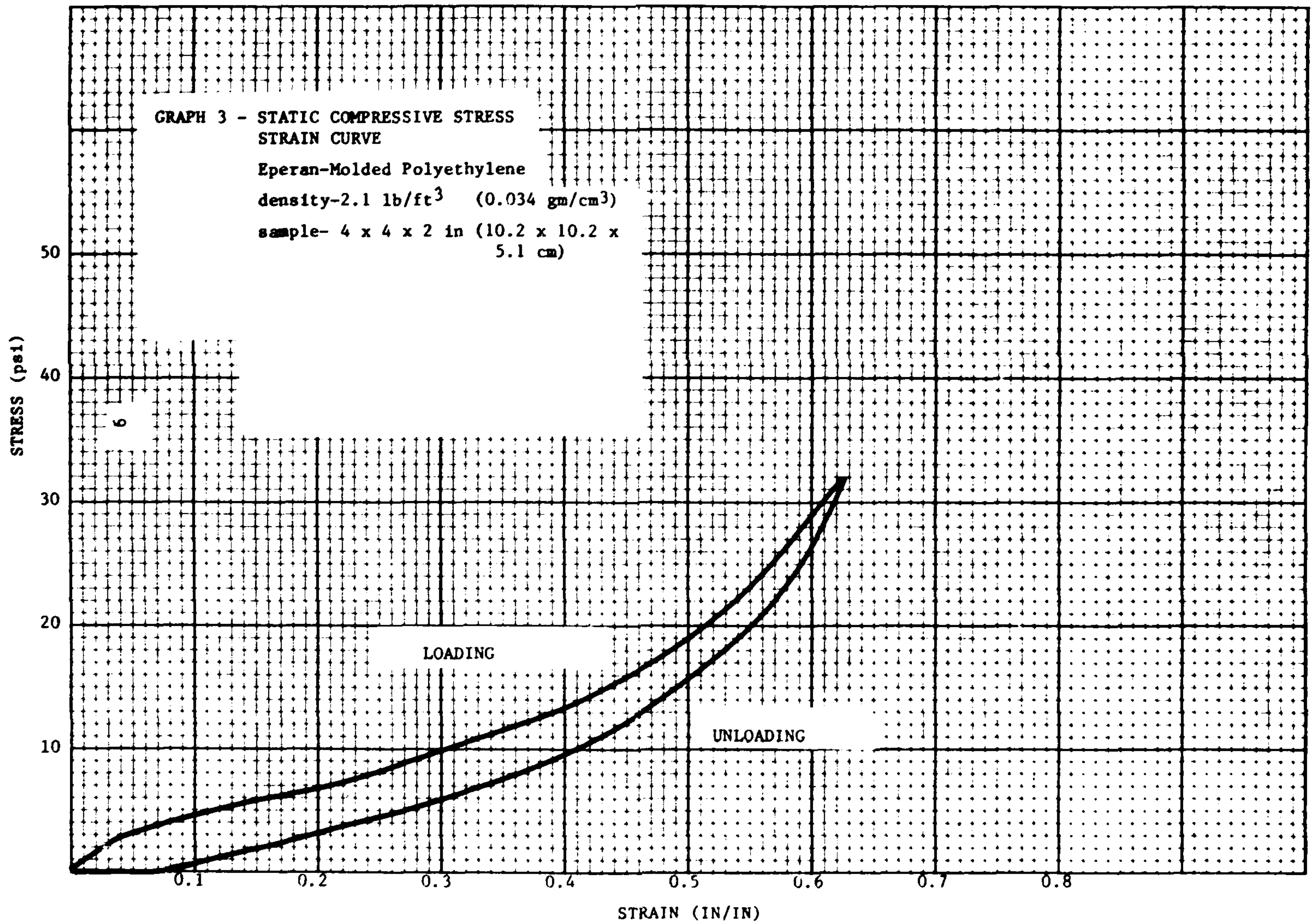
Compression Set

The compression set of the material was determined in accordance with PPP-C-1752A, "Cushioning Material, Packaging, Unicellular Polyethylene Foam, Flexible", for type I material. Three samples were cut to dimensions of 4 x 4 x 1 inch (10.1 x 10.1 x 2.5 cm). Each sample was compressed 35% of its original thickness for 1 hour. One hour after removing the load, the sample thickness was measured. The compression set was determined from the following formula:

$$\text{compression set (percent)} = \frac{(t_o - t_f) \times 100}{t_o}$$

Where: t_o = original thickness

t_f = final thickness measured one hour after load removal


GRAPH 3 - STATIC COMPRESSIVE STRESS STRAIN CURVE
Eperan-Molded Polyethylene
density-2.1 lb/ft^3 (0.034 gm/cm^3)
sample- 4 x 4 x 2 in (10.2 x 10.2 x 5.1 cm)
LOADING
UNLOADING
STRESS (psi)
10
20
30
40
50
STRAIN (IN/IN)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

Compressive Strength

The compressive strength of the material was determined in accordance with PPP-C-1752A for type I material. Three specimens 4 x 4 x 1 inch (10.1 x 10.1 x 2.5 cm) were compressed 10% of their original thickness at a rate of 0.5 inch (1.3 cm) per minute. The load was read at 10% compression and this value converted to pounds per square inch.

Temperature Effects (dynamic)

To observe the effects of temperature on the dynamic characteristics of EPERAN, the following tests were conducted. Two and three inch (5.1 and 7.6 cm) thick samples 8 x 8 inches (20.3 x 20.3 cm) were tested using the same method as used to develop the peak G vs. static stress curves. Only one static stress point was evaluated (0.6 lb/in^2 (0.042 kg/cm^2)). A drop height of 30 inches (76.2 cm) was maintained for all drops. Five drops were conducted on each sample at 72°, -20°F, 72°F, 120°F and 72°F in that order, using the same procedure as described above.

RESULTS

Dynamic Impact Test

The results of the dynamic tests are presented in Graph 1. The curves indicate that, the EPERAN material provides lower peak G values than the 2.0 lb/ft^3 (0.034 gm/cm^3) polyethylene in the optimum cushioning static stress range. The data for the 2.0 lb/ft^3 (0.032 gm/cm^3) polyethylene material was taken from MIL-HDBK-304A.

A comparison of the Peak G vs static stress data developed by this Agency with that developed by the manufacturer indicated some differences. The differences may be due to variations in the test methods or slight material variations. The comparisons were made at the 23.6 inch (60 cm) and 29.5 inch (75 (cm) drop heights. A curve developed for 1.6-inch (4.cm) thick material at a drop height of 23.6 inches (60 cm) indicated that this Agency's data was 20% higher than the Japanese data in the optimum cushioning static stress range.

Completed Pack Test (Corner Pads)

The results of all corner pad testing in the completed pack configuration at drop heights of 15.7, 19.7, and 23.6 inches (40, 50, and 60 cm) indicated that the manufacturer developed peak G-static vs. stress curves could safely be used for designing corner pads.

The drop tests conducted, on the molded corner pads 0.79 inch (2 cm) thick, at drop heights of 15.7 and 19.7 inches (40 and 50 cm) indicated that they would hold up very well. A second corner drop on one corner is the most hazardous situation because of the container's corner being crushed on the first drop. The relatively thin material does allow the design "G" level to be exceeded on the second drop. The thicker material corner pads did experience some increase in G level on the second corner drop but did not exceed the design value.

The results of the drop tests using the "in-house" fabricated corner pads of 1.6 and 2.4 inch (4 and 6 cm) thicknesses correlated very well with the dynamic curves developed by this Agency for a 23.6 inch (60 cm) drop height. The pads held up well for the number of drops (45) made on them.

Static Compressive Stress-Strain Curve

The stress-strain curve (average of 3 samples) is presented in Graph 3. As indicated by the "unloading" curve the material exhibited good recovery after 62.5% compression. Also, as indicated by the "loading" curve, deformation of 2% or less occurs when the material is loaded to its optimum static stress range of .3 psi (.02 kg/cm^2(to 1.5 psi (.11 kg/cm^2).

Compression Set

Specification PPP-C-1752A for unicellular polyethylene foam allows for a maximum set of 10% of the original thickness. Eperan has an average set of 3%, which indicates excellent recoverability.

Compressive Strength

PPP-C-1752A allows for an 8 lb/in^2 (0.056 kg/cm^2) maximum compressive strength. The average compression strength for the Eperan material was 6.7 lb/in^2 (0.47 kg/cm^2).

Temperature Effects (Dynamic Cushioning)

The following table presents the results of the temperature tests for 2 and 3-inch (5.1 and 7.6 cm) thick samples:

Temp.		2 in (5.1 cm) sample	3 in (7.6 cm) sample
(°F)	(°C)	Avg. Peak Gs	Avg. Peak Gs
72	22.2	52.7	38.3
-20	-28.9	57.0	46.7
72	22.2	55.3	39.7
120	48.9	58.7	39.5
72	22.2	56.2	39.2

In general, the results indicate that the effects of temperature extremes on dynamic cushioning performance are minimal. The only change of any significance occurred at -20°F for the 3 in (7.6 cm) thick material.

The results for the 1.6 and 2.4-inch (4 and 6 cm) thick samples are shown in the following table:

Temp. (°F)	Temp. (°C)	1.6 in (4 cm) sample (Avg. Peak Gs)	2.4 in (6 cm) sample (Avg. Peak Gs)
72	22.2	63.0	44.5
-60	-51.1	69.2	51.2
72	22.2	67.2	46.7

The average peak G values for both samples thicknesses increased a little over 6 Gs. Some of the increase may have been due to repeated impacts. The material did not crack or show any signs of degradation due to the effects of temperature.

DISCUSSION

Dynamic Characteristics

The results of the dynamic tests indicate that the cushioning properties of Eperan are equal to or better than 2 lb/ft^3 (0.032 gm/cm^3) polyethylene sheet stock material when used in the optimum cushioning static stress range. The ability to mold the material in a variety of forms and shapes enhances its potential applications as both a cushioning and container material.

CONCLUSIONS

From the data collected in this study it is concluded that:

1. Molded polyethylene has a potential use as a cushioning and/or a blocking and bracing material in package designs.

2. The molded polyethylene material will provide superior cushioning performance in the higher static stress ranges associated with most applications of polyethylene materials.

3. The greatest potential benefit with this material appears to be in those applications which require the use of built-up cushion pads or container structures formed by laminating together pieces of polyethylene sheet stock. Where volume production is required, the substitution of molded polyethylene in these applications should prove to be cost effective through the reduction of labor requirements.

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Expanded Bead Molded Polyethylene Foam Cushioning Material was evaluated for its static and dynamic characteristics. It was determined that the material meets the compression set and compressive strength requirements of Type I material of PPP-C-1752A, "Cushioning Material, Packaging, Unicellular Polyethylene Foam, Flexible." The material provides slightly better dynamic cushioning in the optimum cushioning static stress range than conventional polyethylene sheet stock materials. Application of molded polyethylene should (Cont'd)

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